The conservation status of the Black Grass-dart Butterfly *Ocybadistes knightorum:* a species at risk from climate change

Mick Andren and Mark A. Cameron

Ecosystems and Threatened Species Unit, Northern Branch, New South Wales Office of Environment and Heritage, Loocked Bag 914 Coffs Harbour, New South Wales 2450, Australia.

Email: mick.andren@environment.nsw.gov.au

ABSTRACT

The Black Grass-dart Butterfly *Ocybadistes knightorum* has a highly restricted distribution along the New South Wales north coast and is listed as an Endangered species in the State. Recent surveys have dramatically increased the known distribution of the species, warranting a reassessment of its conservation status. Fine-scale mapping of the entire known habitat of the species enabled a detailed assessment to be conducted that was commensurate with the small size of the butterfly and the fine-grained environmental data available. We evaluate the status of *O. knightorum* against IUCN Criteria B (Geographic Range). The butterfly was found to have an extent of occurrence of 312 km^2 and an area of occupancy of 76 km^2, at three locations. A detailed digital elevation model was used to demonstrate the likelihood of continued decline due largely to sea-level rise induced by climate change. An estimated 85% of the current habitat of *O. knightorum* will become unsuitably saline by 2100 according to the best currently available sea-level rise prediction. Weed invasion and anthropogenic disturbance are also serious threats, contributing to continued decline in some areas. Adopting a precautionary approach, we assess the species as Endangered under IUCN criteria.

Key words: butterfly conservation, sea-level rise, threatened Lepidoptera, IUCN criteria, climate change

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Introduction

The Black Grass-dart Butterfly *Ocybadistes knightorum* is a subtropical narrow-range endemic species of the New South Wales (NSW) north coast. Three previous assessments of its conservation status have been undertaken. In 2000, Braby assessed the species as Vulnerable at a national level, largely due to its restricted distribution and the threat posed by introduced weeds (Braby 2000). Sands and New (2002) evaluated the conservation status of *O. knightorum* in the Action Plan for Australian Butterflies. They also found the species to be nationally Vulnerable, based on: (i) few breeding populations in protected areas; (ii) small number of populations (five known at the time) and small range of occurrence; and (iii) management that was inadequate for reducing the risks of extinction in the longer term (Sands and New 2002). It was the only butterfly species in NSW that was sufficiently well-known at the time to be considered threatened at the national level (Sands and New 2002). *O. Knightorum* was not, however, listed under the national *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*.

Finally, *O. knightorum* was assessed by the NSW Scientific Committee in 2002 and as a result listed as an Endangered species in NSW in that year. They found that the butterfly occurred in only a few small discrete patches (all threatened by weed invasion) and likely to become extinct unless the factors threatening its survival cease to operate (NSW Scientific Committee 2002).

A substantial amount of new information has recently been generated for *O. knightorum* (Andren and Cameron 2012) that warrants a reassessment of its conservation status. This includes extensive field survey and highly detailed mapping of its distribution, as well as the collection of data on threats, including weed invasion and climate change.

Climate change is recognised as a threat to Lepidoptera (New 2011; Wilson and Maclean 2011) and narrow range endemics may be particularly vulnerable (New 2008). The clear threat to *O. knightorum* is from rising sea levels (New 2011), since the habitat of the species sits directly above the king tide mark. On the north coast of NSW, there is predicted to be a rise in sea level of 0.9 m above the 1990 level by 2100 (DECCW 2009). Although the science on which this estimate is based is rapidly-evolving, it was recently reviewed and still found to be adequate (NSW Chief Scientist and Engineer 2012).

A very fine-grained digital elevation model was available for most of the *O. knightorum* habitat mapped by Andren and Cameron (2012). The elevation model was derived from remotely-sensed Light Detection and Ranging (LiDAR) data (CHCC 2007). The investigation of the utility of LiDAR to characterise habitat is a rapidly-developing area of ecological inquiry (Vierling *et al.* 2008) and it was a key aim of this study to apply LiDAR to the exploration of the potential impact of sea-level rise on the butterfly.

International Union for Conservation of Nature (IUCN) Red List criteria (IUCN 2011) are widely accepted internationally (Miller *et al.* 2007) to assess conservation status and have been extensively applied to butterflies (Lewis and Senior 2011). The criteria have been used to assess a significant number of Australian animals (e.g. Moseby *et al.* 1999; Morris 2000; Harris and Goldingay

2005; Groom 2010; Ward *et al.* 2011), including Australian Lepidoptera (Sands and New 2002; Eastwood *et al.* 2008; Braby and Nielsen 2011).

Here we use the IUCN criteria to reassess the conservation status of *O. Knightorum.* These criteria not only have international currency, but have also been heavily borrowed by both the NSW and Australian governments. They are therefore the most relevant criteria for assisting the assessments at all these levels of governance.

Methods

The Study Area is a section of the NSW coast from Woolgoolga to Scotts Head and is described in detail in Andren and Cameron (2012). All known occurrences of Floyd's Grass *Alexfloydia repens*, food plant of *O. Knightorum* were mapped by Arden and Cameron (2012), providing an accurate depiction of the potential habitat of the butterfly. The habitat is located in two regions (see Fig. 1 below); Sawtell (containing 94% of the habitat) and Warrell Creek. The habitat is generally very low-lying, with the exception of two headland occurrences.

After consideration of the IUCN criteria, it was apparent that Criteria B (Geographic Range) was the most suitable for the assessment of *O. knightorum.*

B1. Extent of occurrence: A simple minimum convex polygon that encompassed all the potential habitat mapped by Andren and Cameron (2012) was used to calculate the extent of occurrence. Andren and Cameron mapped the habitat by manually walking the boundary of most of the 293 known habitat patches with a hand-held GPS. With good satellite coverage, the GPS used was accurate to 1m; all patches that were $1m^2$ or greater were mapped.

B2. Area of occupancy: The Andren and Cameron (2012) mapping was also used as the basis for calculating area of occupancy. While *potential* habitat was mapped, since over 97% of it was found to be occupied by *O. knightorum*, all potential habitat was included in this assessment. The area was scaled up in order to ensure that the assessment against the criteria thresholds was evaluated at the appropriate scale, as recommended in the IUCN guidelines (IUCN 2011). This was achieved by overlaying the habitat map with a 2 km grid and then counting each occupied 4 km^2 grid cell.

B(a) Number of locations: The recommendations in the IUCN guidelines (IUCN 2011) were followed to interpret the number of locations. Threats were identified and the location of likely impacts considered spatially, with reference to the mapping of Andren and Cameron (2012).

B(b) Continuing decline in (ii) area of occupancy, (iii) area, extent and quality of habitat, (iv) number of locations or subpopulations, (v) number of mature individuals: Historical decline has not been documented, but can be partly inferred from the observed extent of weed invasion of habitat patches. Some preliminary data was collected on the magnitude of the threat due to weed invasion of the two most serious weeds, Lantana *Lantana camara* and Broad-leaved Paspalum *Paspalum mandiocanum*. Anecdotal observations suggest that these weeds have actively invaded habitat patches (M. Smith pers. comm. 2010, NPWS; M. Andren pers. obs. 2012). The two weeds were recorded as absent, present or abundant (weeds were considered to be abundant if they affected 30% of the patch, estimated subjectively) for each patch in the Sawtell population.

The mapping of Andren and Cameron (2012) showed that the habitat of *O. knightorum* is very low-lying, making it highly susceptible to any rise in sea level. Future decline is therefore estimated using an analysis of the impact of the 0.9 m sea-level rise predicted by 2100 (DECCW 2009).

LiDAR data was available for most of the Sawtell area. A digital elevation model of the ground surface had been derived from the raw LiDAR data, referenced to the Australian Height Datum (based on Ausgeoid98) and vertically accurate to 15-35 cm (CHCC 2007). The data were used to estimate height above Mean Sea Level (MSL) and used to derive an elevation profile of *O. knightorum* habitat for two scenarios: (i) current MSL; and (ii) assuming a 90 cm rise in MSL by 2100.

This is an admittedly simplistic approach given the extreme complexity of global climate change and its interactions with local conditions on the NSW coast. However, it at least provides an approximate prediction within the limitations of our current state of knowledge.

Results

Following are the results of the assessment against IUCN Criteria B (Geographic range).

B1. Extent of occurrence: The extent of occurrence of *O. knightorum* is 312 km^2 (Fig. 1). This is a significant overestimate as it includes some ocean and very extensive unsuitable areas such as those that have been highly modified by urban and rural development. Nonetheless *O. knightorum* easily qualifies as Endangered under this criterion (well below the 5,000 km^2 threshold).

B2. Area of occupancy: The total area of habitat mapped by Andren and Cameron (2012) is 0.324 km^2 (the yellow area in Fig. 1). When the 4 km^2 grid was overlain, habitat was found to occur in 19 grid cells, equating to an area of occupancy of 76 km^2. Since this is well below the 500 km^2 threshold, *O. knightorum* again easily qualifies as Endangered under this criterion.

B(a) Number of locations: While the mapping of Andren and Cameron (2012) identifies 293 habitat patches, this mapping is far more detailed and comprehensive than that usually available to assess conservation status. Most of the patches are very small and poor or zero butterfly habitat value; *O. knightorum* was absent from 48% of them at the time of sampling. The total area (32.4 ha) is still minor when compared with most other species. Despite the discovery of a second population at Warrell Creek, the habitat remains highly concentrated, with about 75% of it located along a single 7 km stretch of Pine Creek.

A location is defined by the IUCN (2011) as "a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present". Under this definition, the 293

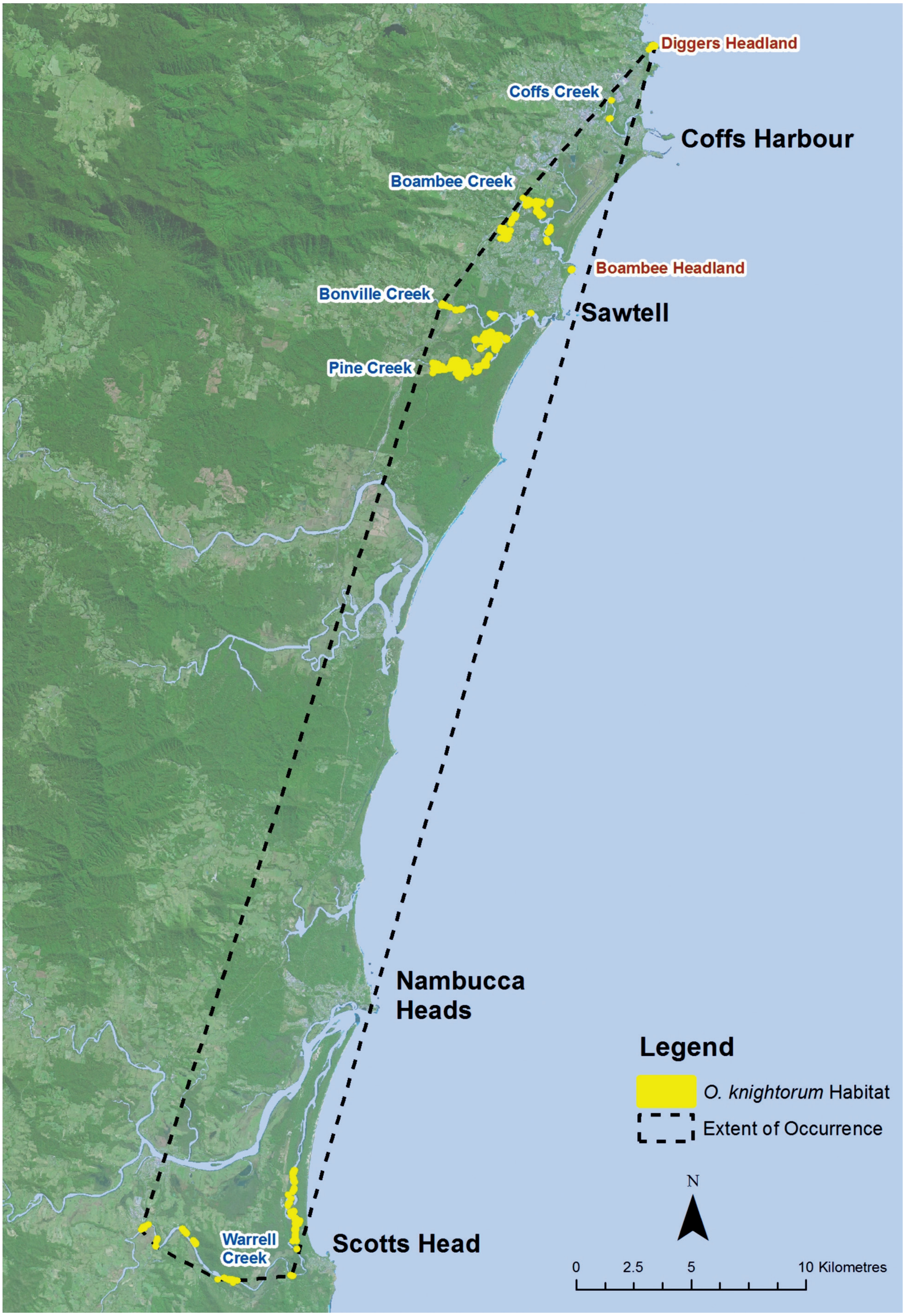

Figure 1. The extent of occurrence of *O. knightorum*, calculated as 312 km^2 using the simple minimum convex polygon shown. Note that the *O. knightorum* habitat area has been accentuated with a thick yellow outline for display purposes.

patches are not all separate locations. Sea-level rise is a clear threatening event that will impact *O. knightorum*. It will affect virtually all the low-lying patches by 2100 (see analysis below). Only the two headland populations will not be impacted by this threat. However, each small headland population (in total only 0.4 ha in size or 1% of the total habitat) could easily be affected by a single threatening event, such as fire, weed invasion or competition from native plants.

We therefore feel justified in taking a precautionary approach to the interpretation of this criterion. The analysis of sea-level rise (below) demonstrates that all of the low-lying populations will be dramatically impacted and we therefore treat these populations as a single "location" under the IUCN definition. Therefore, with the two headland occurrences representing separate locations, there are a total of three locations for the species. As this is less than five locations, *O. knightorum* qualifies as Endangered under this criterion.

B(b) Continuing decline in (ii) area of occupancy, (iii) area, extent and quality of habitat, (iv) number of locations or subpopulations, (v) number of mature individuals: The prevalence of invasive weeds provides circumstantial evidence of recent decline (Fig. 2). In the Sawtell population, *L. camara* was recorded in 102 patches (63%) and *P. mandiocanum* in 72 patches (45%). *L. camara* was considered to be abundant in 64 (40%) of patches and *P. mandiocanum* in 43 (27%) of patches. The evaluation of these estimates needs to be tempered by the difficulty encountered in assessing larger patches due to the amount of internal variation that often occurred throughout the patch. Other weeds recorded less frequently included Ochna *Ochna serrulata*, Senna *Senna pendula*, Trad *Tradescantia fluminensis*, Plantain *Plantago lanceolata* and Rhodes Grass *Chloris gayana*.

About 80% of the mapped *O. knightorum* habitat was covered by the digital elevation model derived from the LiDAR data that was available for the Sawtell area. The current elevation profile (Fig. 3) shows the mean elevation of current butterfly habitat above MSL is 1.63 ± 0.84 m. Most of the habitat (over 90%) is between 1 m and 2 m above MSL. We also consider from our observations that this elevation profile is likely to be representative of those areas not covered by the LiDAR data, with the exception of the atypical headland populations (which are at considerably higher elevation).

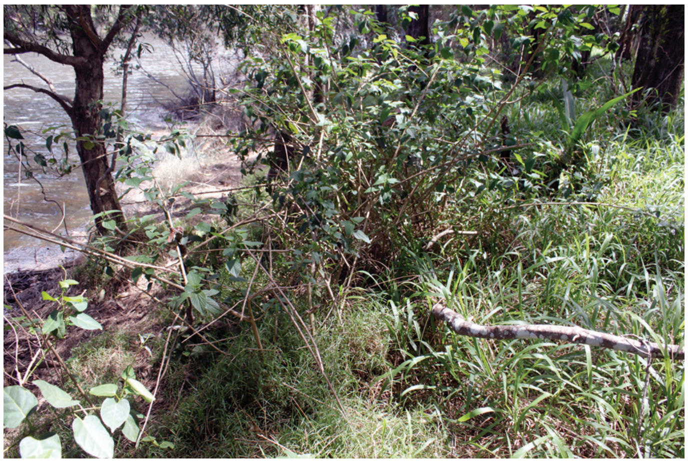

Figure 2. Probable invasion of *A. repens* (fine-leaved grass at bottom centre of picture) by *L. camara* (shrub in centre) and *P. mandiocanum* (broad-leaved grass at lower right hand side). Photo by Mick Andren.

At Sawtell, high tide is often 0.6 m to 0.8 m above MSL, and occasionally about 1.0 m above during the largest king tides or High Higher Water Solstices Springs (HHWSS). Only 7% of the *O. Knightorum* habitat is within this zone of occasional HHWSS tidal inundation, strongly indicating a lack of tolerance by the food plant *A. Repens* for highly saline conditions.

The prediction of the potential impact of sea-level rise on the habitat by 2100 required two major assumptions: (i) the sea level would rise on the NSW north coast by the predicted 0.9 m above the 1990 level; and (ii) *A. repens* would not simply migrate to higher elevations as the sea rises.

There a number of reasons why we suspect that *A. repens* will not be able to easily migrate to higher elevations as the sea level rises. Firstly, the rise is very rapid in geomorphological terms and the alluvial terraces that the species currently occupies will not have time to be reformed at higher elevations. Secondly, in many areas the fact that *A. repens* does not currently occupy the higher sites demonstrates that there are natural restrictions to its spread. Finally, there are many instances where higher elevations are occupied by weeds that are currently invading *A. repens* and would restrict migration.

An additional assumption was that the rise in sea level that has already occurred at Sawtell from 1990 to 2012 has been minor. The exact amount of this rise is unknown and was not therefore taken into account in this analysis. Sea-level is predicted to rise exponentially, in line with rapidly increasing levels of CO_2 in the atmosphere. A small rate initially leads to a maximum rate in 2100 (interpreted from Church *et al.* 2011). The rise from 1990 to 2012 is therefore expected to be small. Global sea levels have been measured to have risen by about 5 cm from 1990 to 2010 (Church *et al.* 2011), so we may have over-estimated the effect by about this amount. This is minor when compared to the overall uncertainty in the predictions and would not significantly alter our findings.

Based on the assumptions above, a hypothetical profile 0.9 m above the current one (i.e. at the future predicted MSL) was used to calculate the area of current habitat that would become too saline by 2100 (Fig. 4).

Assuming the assumptions hold, 85% of the current habitat would be inundated or too saline for *A. repens* by 2100. Furthermore, the remaining 15% would be located in thin strips of isolated marginal habitat that would be unlikely to be high quality for the butterfly. A visual example of the impact of sea-level rise on *O. knightorum* habitat is shown in Fig. 5.

Discussion

Sands and New (2002) assessed *O. knightorum* against 1994 IUCN criteria, modified in a way that they considered suited Australian butterflies, and found the species to be Vulnerable. For very different reasons, we assessed *O. knightorum* as Endangered under IUCN criteria B1B2(a)(b). Sands and New (2002) identified threats of habitat

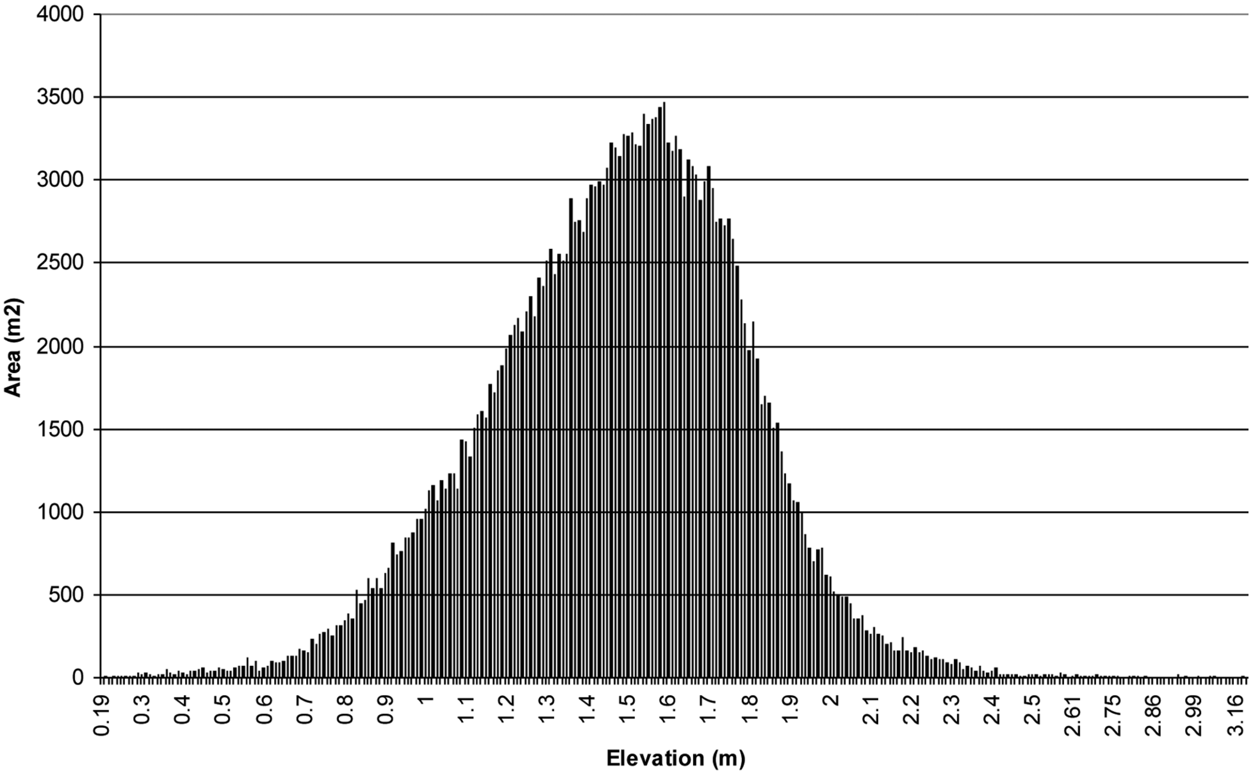

Figure 3. The current elevation (height above Mean Sea Level) profile of *O. knightorum* habitat in the Sawtell population. The data were derived from LiDAR and covered approximately 80% of the known habitat. The atypical headland occurrences were deliberately omitted from the analysis.

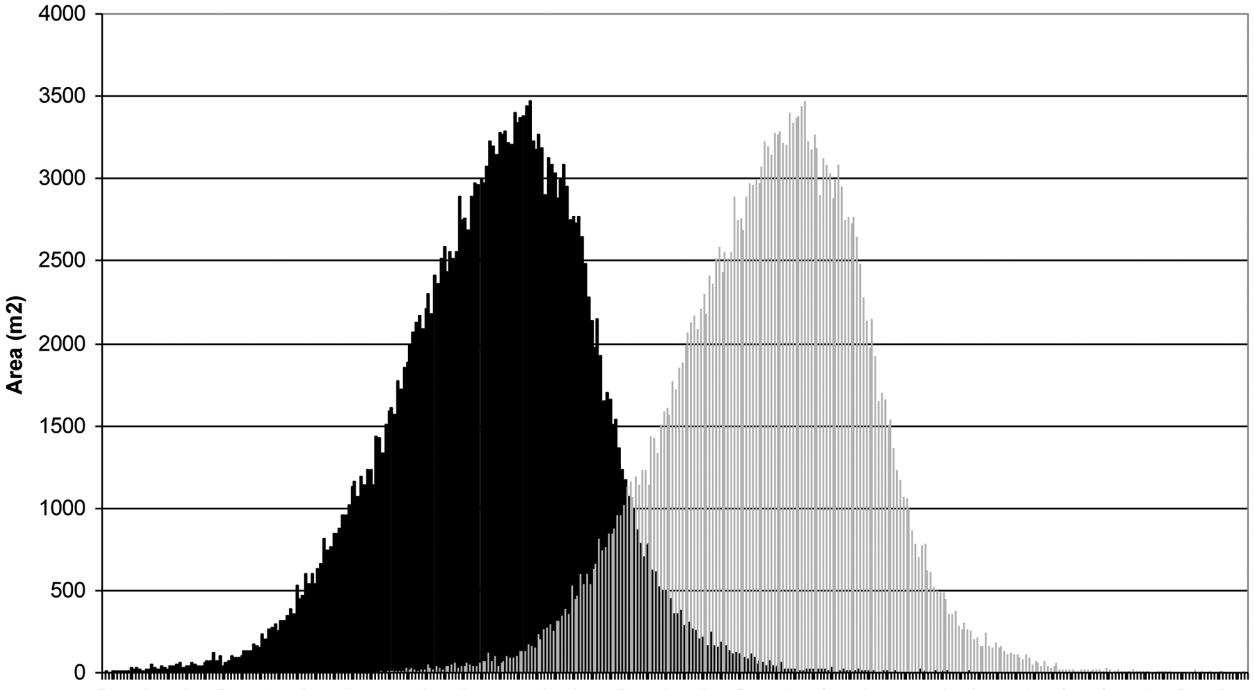

Figure 4. The current elevation profile of *O. knightorum* habitat (black) and a hypothetical profile 0.9 m higher at the future predicted sea level height in 2100 (grey). If the food plant *A. repens* cannot migrate to the higher elevation, then the only part of the current profile that would not become too saline is the area of overlap (15% of the current distribution).

disturbance, fire and weed invasion. We crucially added the threat of sea-level rise. Their citing of only five known sub-populations (and only two of them in protected areas) has been superseded by new information. Conducting research followed by periodic reassessments of conservation status is a positive process that generates a dynamic, rather than static list of threatened invertebrates (see New and Sands 2003).

Criteria B1B2(a)(b) were easily met, except for B(a) "number of locations less than five". A precautionary

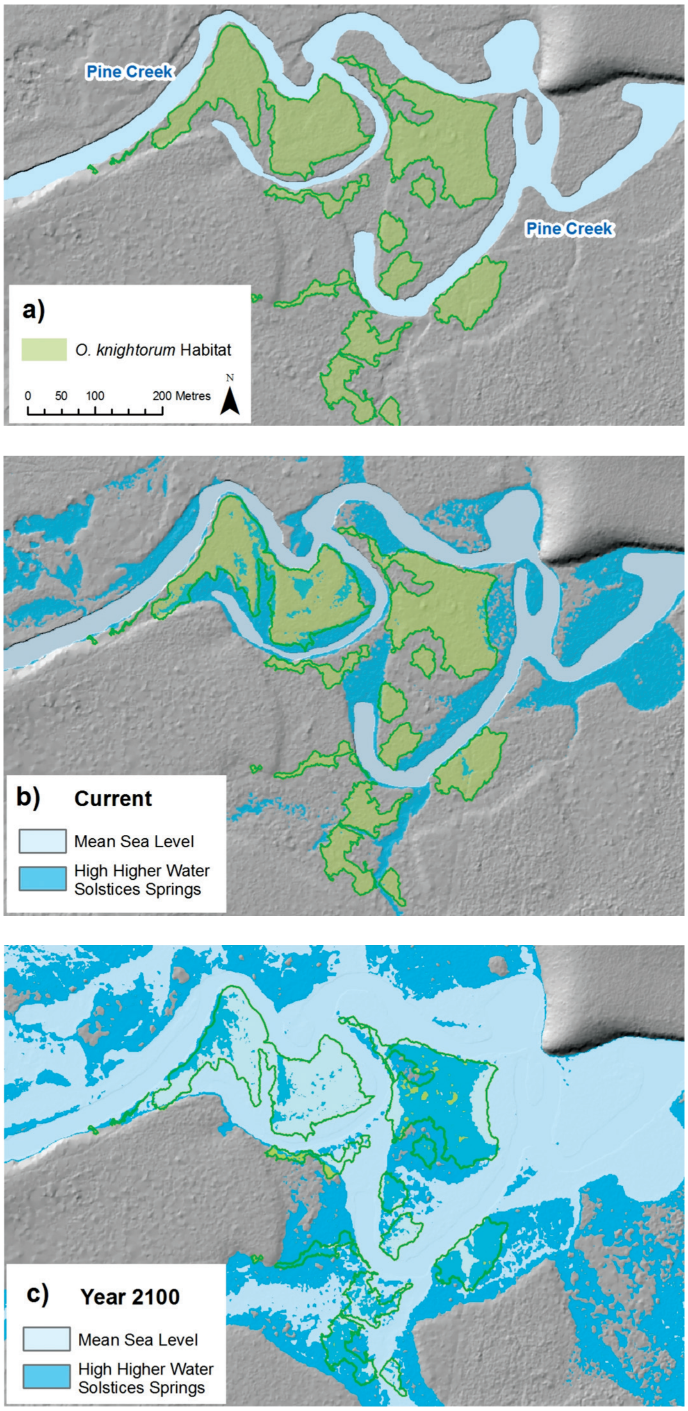

Figure 5. Predicted impact of sea-level rise on habitat mapped at the "Shark's Head" in Bongil Bongil National Park, perhaps the single most significant known population of *O. knightorum.* (a) Terrain derived from LiDAR overlain by current *O. knightorum* habitat. (b) Current habitat overlain by current High Higher Water Solstices Springs (HHWSS), or highest king tide. Very little of the current habitat is inundated by this tide level, indicating intolerance of the food plant *A. repens* to saline conditions. (c) Predicted inundation following a projected sea-level rise of 0.9 m by 2100 (i.e. 0.9 m added to current Mean Sea Level (MSL) and HHWSS). Much of the habitat is inundated by the rise in MSL and nearly all by HHWSS, including the core high quality habitat. The small and isolated patches remaining above HHWSS are not high quality butterfly habitat.

interpretation of this criteria resulted in three "locations" being identified. The species would change to "Near Threatened" if a less precautionary interpretation was adopted. Indeed, the quantum increase in the known distribution would possibly have resulted in an assessment of "Least Concern" had it not been for the high likelihood that *O. knightorum* will be severely affected by climate change.

The ability to forecast the likely impact of sea-level rise on *O. knightorum* is one of the benefits derived from undertaking habitat mapping at a very fine scale. Butterflies respond to fine-scale stimuli and data should be collected at an appropriate scale (Dennis *et al.* 2006). The detailed mapping allowed utilisation of the full potential of the high resolution digital elevation model derived from LiDAR. Despite this, we stress that the forecast we have made here is necessarily simplistic given the infinite complexity of the issues involved. However, we believe it offers the best available basis for this conservation assessment.

The predicted 0.9 m sea level rise by 2100 (DECCW 2009) is likely to be catastrophic for *O. knightorum*. An estimated 85% of the current habitat is likely to become unsuitably saline and the remaining 15% likely to be low quality butterfly habitat. New (2008) argued that narrow range endemics may be particularly vulnerable to relatively sudden climatic changes. *O. knightorum* may struggle to survive such extreme habitat loss, as it has not demonstrated a capacity

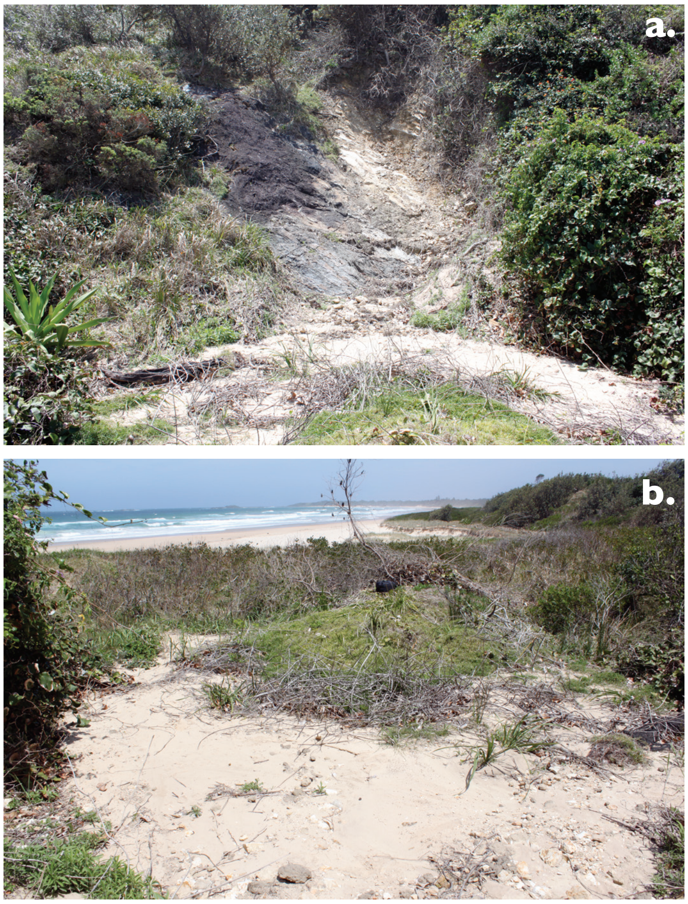

Figure 6. (a) A slump on Boambee Headland caused by flooding rains in 2009 that translocated a patch of *O. Knightorum* habitiat onto (b) the foredune of Sawtell Beach. Photos by Mick Andren.

to migrate quickly to higher elevations. As a first step in developing a sea-level rise adaptation strategy, potential sea-level rise refugia need to be identified for the species.

Other aspects of climate change that could impact on *O. knightorum* populations were beyond the scope of this study to properly assess. There is also predicted to be an increase in the frequency, height and extent of flood events under the currently accepted climate change scenario (DECCW 2010). This is likely to impact the low-lying, riparian habitat. During this study, one small patch was largely lost and another severely impacted (Fig. 6) by a major flood on 31 March 2009. The loss and gain of habitat, while a natural process, is exacerbated by the degree of dynamism of the climatic forces operating on the small habitat patches.

Fire regimes may also be modified by climate change. Increased evaporation and drier conditions in winter are predicted to occur on the NSW north coast (DECCW 2010), which will lead to seasonal alterations in fire frequency and intensity. Immature stages of *O. knightorum* may be unable to escape intense fires (D. Sands pers. comm. 2010). Therefore fires that occur early in the season (e.g. August or September) may result in severe impact if there are few butterflies in the adult stage that are able to escape. Some of the best habitat is associated with peat formations (Sands 1997), increasing susceptibility to fire. At least one patch has experienced a protracted burn consistent with a peat fire (M. Smith pers. comm. 2010, NPWS).

Butterflies may be affected by higher temperatures. Two woodland species have been shown to have lower longevity and fecundity in high temperature regimes (Karlsson and Wiklund 2005). The hotter predicted temperatures on the NSW north coast under climate change (DECCW 2010) may therefore also have a detrimental impact on *O. knightorum*.

The crucially important Pine Creek and Bonville Creek catchments (containing 79% of the known habitat) are subject to impoundment, although this has rarely occurred in the recent past. The creek mouth closed in 2012 for the first time in over 50 years and increased water levels in both catchments. Fig. 7 shows the inundation of *A. repens* habitat and the impact on the grass; a portent of what would occur under increased sea levels.

Invasion by introduced weeds, particularly *L. camara* and *P. mandiocanum*, had previously been identified as a major threat to the habitat quality of *O. knightorum* (Braby 2000; Sands and New 2002) and in developed catchments there is a significant threat posed by anthropogenic disturbance (Andren and Cameron 2012). These threats continue to operate.

In the Sawtell population, *L. camara* occurred in 63% of patches, with significant infestations in 32% of patches, while *P. mandiocanum* occurred in 50% of patches, with significant infestations in 23% of patches. Habitat quality is of fundamental importance for the maintenance of butterfly populations (Thomas *et al.* 2001; Wood and Pullin 2002; Dover and Settele 2009). In many instances, improving the quality of habitat can be more important for butterfly conservation than, for example, increasing habitat size or connectivity (WallisDeVries 2004). To this end, it is vital that weeding programs are maintained and expanded.

O. knightorum is a significantly more threatened species than its food plant *A. repens*. Not only is the butterfly apparently absent from many small *A. repens* patches, but it is likely that the plant has a greater ability to recover from inundation or fire than the butterfly, particularly if the impact occurs when the butterfly is in less mobile stages of its life-cycle. Furthermore, while *A. repens* can occupy low quality environments, it is not vigorous and does not provide good quality butterfly habitat. *O. knightorum* is often absent from these occurrences of its food plant (M. Andren pers. obs. 2012).

On a more positive note, *O. knightorum* is a species where active management can play a successful role in securing its long-term persistence. The degree to which *O. knightorum* habitat is contained in protected areas is high (Andren and Cameron 2012) and the threat from weed invasion is being managed in some reserves where key patches have responded well to weeding, providing a number of luxuriant examples of successful habitat rehabilitation.

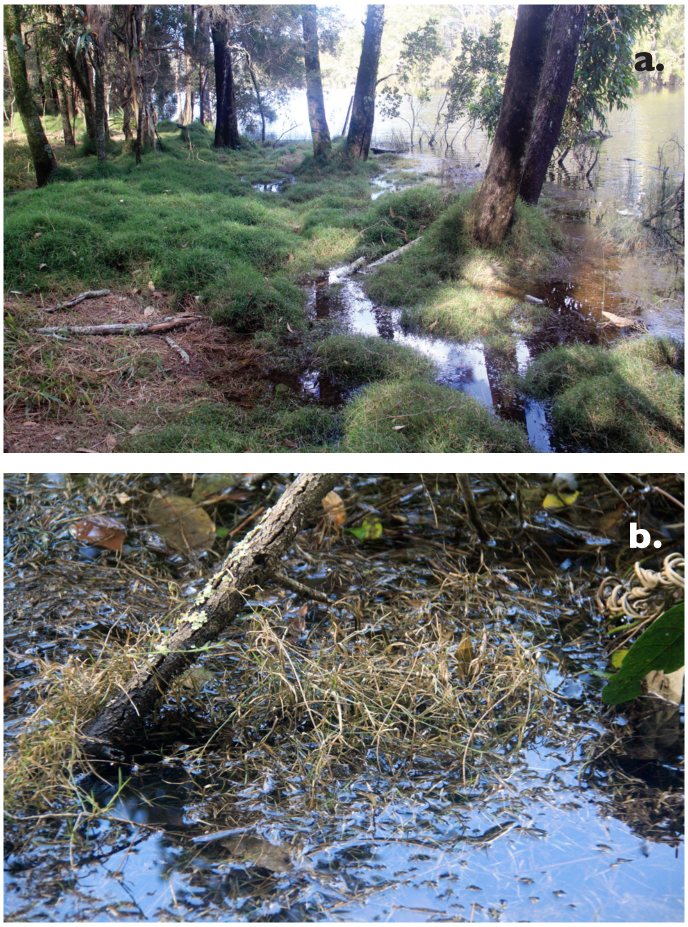

Figure 7. (a) Inundation of *A. repens* due to the impoundment of Bonville Creek in October 2012. (b) *A. repens* dying due to inundation. Photos by Mick Andren.

The existence of the headland populations demonstrates that the typical swamp forest habitat is not obligatory for either *A. repens* or *O. knightorum*. This suggests that the fundamental niche of both species is considerably broader than that realised across most of their current distribution. Translocation of *A. repens* has been successful on four occasions and *O. knightorum* occupies all four translocated patches (Andren and Cameron 2012). It is not known whether the butterfly was inadvertently translocated with its food plant, or later colonised the translocated patches. Regardless of the dispersal mechanism, the translocations are highly successful. *O. knightorum* is a species that need not become extinct in future.

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